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Viscosity of Gaseous Mixtures of HFC-125 + HFC-32

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Abstract

This paper reports experimental results for the viscosity of gaseous mixtures of HFC-125 (pentafluoroethane) + HFC-32 (difluoromethane). The measurements were carried out with an oscillating-disk viscometer of the Maxwell type at temperatures from 298.15 K to 423.15 K. The viscosity was measured for three mixtures(mole fraction of HFC-125 is 0.7498,0.4998 or 0.2475). The viscosity at normal pressure was analyzed with the extended law of corresponding states developed by Kestin et al. and the scaling parameters were obtained for unlike-pair interactions between HFC-125 and HFC-32. The modified Enskog theory developed by Vesovic and Wakeham was applied to predict the viscosity for the binary gaseous mixtures under pressure. As for the calculation of pseudo-radial distribution function in mixtures, we proposed a method based on the Carnahan-Starling equation for the radial distribution function of hard sphere mixtures.

Keywords : Corresponding states; Enskog theory; HFC-125; HFC-32; Mixture model; Viscosity

1. INTRODUCTION

The chlorofluorocarbons(CFCs) and hydrochlorofluorocarbons(HCFCs) must be completely phased out in the near-future. The potential alternatives proposed are the hydrofluorocarbons (HFCs), such as HFC-125 (pentafluoroethane), HFC-134a(1,1,1,2-tetrafluoroethane), HFC-143a (1,1,1- trifluoroethane), and HFC-32 (difluoromethane), and their binary and/or ternary mixtures.

Transport properties, such as viscosity, of the alternative refrigerants influence the economical feasibility of heat exchangers which can show close to the theoretical efficiency of the thermodynamic cycle with the CFCs. Therefore, reliable prediction methods for the transport properties of mixed HFCs are required to establish the process design methodology for a search of the optimum operation conditions of the refrigeration systems with the use of HFCs.

In our previous studies, we measured the gaseous viscosity of HFC-32,HFC-134a,HFC-143a,HFC-125[1-4] and HFC-125+HFC-134a systems[5]. As part of a continuing study of the viscosity of dense fluid systems containing HFCs, measurements of the viscosity of gaseous mixtures of HFC-125+HFC-32, made between 298.15 and 423.15 K at pressures up to 6.6 MPa, are reported in this paper. The viscosity data at 0.1 MPa were used to determine the scaling parameters of the unlike-pair interactions between HFC-125 and HFC-32 from the extended law of corresponding states[6]. The viscosity data under pressures were analyzed with the extended Enskog theory developed by Vesovic and Wakeham[7]. We proposed a newly method to determine the pseudoradial distribution function for species i and j in the mixture.

2. EXPERIMENTAL

The viscosity was measured with an oscillating-disk viscometer of the Mawell type. The gas density at the experimental conditions of the viscosity measurement was measured with a high-pressure gas pipette. The experimental apparatus and procedure were the same as those described in previous studies [8-10]. The apparatus constant of the

viscometer at the experimental temperature and pressure conditions was determined by considering the viscosity data of nitrogen taken from Stephan et al.[11] and the nitrogen gas density data from Jacobsen et al.[12]. As for the gas density determination, the second virial coefficient data for the HFC-125 + HFC-32 binary gas mixture reported by Weber [13,14] were used to determine the gas compressibility factor values at the expanded conditions in a glass cylinder in the gas density measurement apparatus [8,9]. The samples were prepared in a sample vessel by charging firstly the less volatile constituent gas (HFC-125) and then the more volatile one (HFC-32). When the sample gas mixture was loaded into the viscometer vessel, the temperature of the sample vessel and the connecting tubing between the sample vessel and the viscometer vessel were thermostated at about 423 K to prevent condensation. Temperature and pressure values have an uncertainty of 0.01 K and 0.5 kPa, respectively. Density values have an uncertainty of 0.05 kg m^{-3}. The compositions of the sample mixtures were determined by weighing. The uncertainty of the composition determination was estimated to be less than 10^{-4} mole fraction.

The HFC-125 and HFC-32 were supplied by Asahi Glass Co. Ltd. The purity of the both samples, certified by the suppliers, were approximately 99.9 mol%. The samples were further purified by distillation several times before preparing mixture samples.

3. RESULTS AND DISCUSSION

The experimental results for viscosity and density of the HFC-125 + HFC-32 system are presented in Table 1. The viscosity values of the mixture of HFC-125(0.4998) + HFC-134a(0.5002) are shown in Figs.1 and 2. As seen in Fig.1, the curves as a function of pressure intersect for the isotherms from 348.15 K to 423.15 K, but the curves as a function of density do not, as seen in Fig.2. Almost the same behavior was observed in the other two mixtures and also for the pure HFCs and HFC-125 + HFC-134a binary systems studied in our previous studies[1-5].

The viscosity of gaseous mixtures at 0.1 MPa, η_0, are plotted as a function of a mole

fraction in Fig.3, in which the viscosity of HFC-125[4] and HFC-32[1] are also shown. As can be seen in Fig.3, the shape of the curves for η_0 is slightly monotonically convex upwards in the present experimental temperature range, which is known to be most general for the viscosity of gaseous mixture at 0.1 MPa.

The extended law of corresponding states for the transport properties was applied to determine the scaling parameters for the binary interaction between HFC-125 and HFC-32. The equations used are the same as given by Kestin et al. [6]. The scaling parameters of HFC-125 and HFC-32 are determined from the least square fitting to the viscosity data for each of the pure HFCs reported previously [1,4]. The optimum values of the scaling parameters between the HFC-125 and HFC-32 pair interaction are determined with the use of the viscosity data measured in this study. The values of the scaling parameters obtained are shown in Table 2. The calculated results with the parameters in Table 2 are shown as the solid lines in Fig.3. The average deviation between the experimental viscosity values and the calculated ones is 0.29 % for an absolute average deviation and 0.86% for a maximum deviation.

The viscosity under pressure is analyzed with the extended Enskog theory developed by Vesovic and Wakeham (V-W method) [7]. In the V-W method, we need the equations for the viscosity of pure constituent gases at 0.1 MPa and under pressures and for mixture gases at 0.1 MPa. The viscosities at 0.1 MPa are obtained from the extended law of corresponding states described above. The viscosities of pure HFC-125 and HFC-32 are calculated with an excess viscosity equation expressed as follows;

$$\eta - \eta_0 = a_1(\rho - \rho_0) + a_2(\rho - \rho_0)^2 + a_3(\rho - \rho_0)^3 \qquad (1)$$

and

$$a_1 = a_{10}T + a_{11} + a_{12}/T \qquad (2)$$

$$a_2 = a_{20}T + a_{21} + a_{22}/T \qquad (3)$$

$$a_3 = a_{30} + a_{31}/T + a_{32}/T^2 \qquad (4)$$

where η is the viscosity under pressure in μPa s, η_0 is the gas viscosity at 0.1 MPa in

μ Pa s, ρ is the gas density under pressure in kg m^{-3}, ρ_0 is the gas density at 0.1 MPa in kg m^{-3}, T is the absolute temperature in K, and a_{ij} are parameters. The values of a_{ij} for HFC-125 and HFC-32 are shown in Table 3. While Eqs.(1)-(4) represent the experimental viscosity values with the absolute average deviations less than 0.20% for HFC-125 and 0.19% for HFC-32 in our experimental region, as shown in Table 4, it should not be used at the temperature and/or density region outside of our experimental conditions. In the V-W method, the mean free path shorting factor, α_{ii}, and the switch-over density are obtained from the following relations.

$$(d\eta_i/d\rho)\,|_T = \eta_i/\rho \qquad (5)$$

In the lower temperature range below 348.15 K, the switch-over densities at which Eq.(5) hold are much higher than the maximum density of the present experimental conditions. Therefore Eqs.(1)-(4) should not be applicable to Eq.(5). Thus the Lee-Thodos (LT) viscosity correlation[15] was applied to Eq.(5). In the LT correlation, we used the extended law of corresponding states to calculate the viscosity at 0.1 MPa and treated the triple point temperature as the adjustable parameter in order to improve the agreements between the experimental viscosity and correlated ones. The optimum value of the triple point temperature was 144.88 K for HFC-125 and 162.06 K for HFC-32.

As for the mixture viscosity calculations, the pseudo-radial distribution function χ_{ij} for species i and j in the mixture should be evaluated. Kestin and Wakeham [16] proposed the equation for χ_{ij} with the use of the density expansion equation for the radial distribution function of hard sphere fluid mixture. Since they used the density expansion equation truncated after second order density terms, the performance of the χ_{ij} equation at high density region is unclear. To overcome this problem, we proposed a new method to calculate the χ_{ij} from the exact theoretical equation for the radial distribution functions for the hard sphere fluid mixture proposed by Carnahan and Starling[17]. As shown by Vesvic and Wakeham [7], the pseudoradial distribution function for pure gases, χ_i, can be obtained from the pure-component viscosity by application of the hard-sphere expression for the viscosity of a pure gas[eqs.(6),(7) in Ref.[7]]. We assumed that the χ_i

is equal to the Carnahan-Starling radial distribution function of pure hard-sphere fluid i as follows.

$$\chi_i(\rho,T) = 1/(1-\xi_3) + 1.5\,\xi_3^2/(1-\xi_3)^2 + 0.5\,\xi_3^3/(1-\xi_3)^3 \quad (6)$$

where ξ_3 is a reduced density defined by $(1/6)\pi\rho N_{AV} d_i^3$, ρ is a molar density in mol/cm^3, N_{AV} is Avogadro's number in mol^{-1}, and d_i is a hard sphere diameter for species i in cm. Once the value of χ_i was obtained from the pure-component viscosity data, the d_i can be determined from solving Eq.(6). Since the hard sphere diameter for every constituent species in the mixture can be determined from Eq.(6), the pseudoradial distribution functions for species i and j in the mixture were obtained from the Carnahan-Starling radial distribution function of hard-sphere mixtures [17]. In the case of binary mixture of species i and j, the following equation is hold.

$$\chi_{ij}(\rho,T) = 1/(1-\xi_3) + 3(d_i\,d_j)\,\xi_2/\{(d_i+d_j)(1-\xi_3)^2\} + 2(d_i\,d_j)^2\,\xi_3^2/\{(d_i+d_j)^2(1-\xi_3)^3\} \quad (7)$$

The reduced density ξ_k (k=2,3) is defined as follows,

$$\xi_k = (1/6)\pi\rho N_{AV}(x_i d_i^k + x_j d_j^k) \quad (8)$$

where x_i is a mole fraction of species i. Since the Cranahan-Starling equation can give superior results for the thermophysical properties for highly dense hard sphere fluids, it is reasonable to consider that we can extrapolate the $\chi_{ij}(\rho,T)$ at higher density region.

The comparison between the calculated results from the Vesovic-Wakeham method with the original mixing rule for χ_{ij} [7] and those with the mixing rule proposed in this study [Eqs.(6)-(8)] are shown in Table 4. It was found that the deviations of the three mixtures from the two mixing rules for $\chi_{ij}(\rho,T)$ are almost the same order. This suggests that the mixng rule for $\chi_{ij}(\rho,T)$ proposed in this study is equivalent to the original mixing rule of Kestin and Wakeham in the present experimental conditions. The ability of the V-W method to represent the density and temperature dependence of the viscosity for

the HFC binary mixture may depend mainly on the viscosity correlations used for pure constituent HFC.

4. CONCLUSION

In this paper, we report the experimental results of the gaseous viscosity for the HFC-125 + HFC-32 system. The scaling parameters for the molecular interaction between HFC-125 and HFC-32 were determined with the extended corresponding state theory and the viscosity data at 0.1 MPa. The viscosity values of the gaseous mixture under pressure were predicted with the modified Enskog theory developed by Vesovic-Wakeham. In order to extend the applicable density region for the modified Enskog theory, we proposed a new method to calculate the pseudoradial distributions based on the exact equation for radial distribution function for hard-sphere fluids developed by Carnahan-Starling. From the comparison between the calculated results and the experimental viscosity values, both the proposed method and the original one can give almost the same results in the present experimental conditions. We can conclude that the Vesovic-Wakeham method should be a reliable method for the viscosity calculation for the mixture of HFCs under pressures in the case when both the viscosities of pure HFCs under pressures and of gaseous HFC mixtures at 0.1 MPa can be correlated with high accuracy.

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Table 1 Experimental viscosity values for the HFC-125(1) + HFC-32(2) system.

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
	$x_{HFC-125} = 0.74985$			323.15	2.3364	132.09	15.337
298.15	0.1033	4.349	13.093		2.4833	147.31	15.647
	0.2271	9.750	13.073	348.15	0.1028	3.688	15.157
	0.3684	16.092	13.063		0.2898	10.561	15.140
	0.4892	21.922	13.051		0.4906	18.199	15.166
	0.5863	26.732	13.051		0.6823	25.769	15.222
	0.7188	33.613	13.050		0.9277	35.899	15.265
	0.8694	41.966	13.086		1.1713	46.220	15.345
	1.0004	49.791	13.114		1.4148	57.296	15.451
	1.1236	57.747	13.198		1.6701	69.581	15.597
	1.3443	73.263	13.294		1.9011	81.449	15.755
323.15	0.1021	3.956	14.064		2.1514	94.856	15.977
	0.2460	9.683	14.110		2.4120	110.46	16.216
	0.3906	15.634	14.096		2.6578	126.57	16.540
	0.5377	21.913	14.100		2.8920	143.35	16.865
	0.6827	28.350	14.139		3.1943	167.59	17.435
	0.8280	35.069	14.177		3.4517	192.04	18.045
	0.9765	42.139	14.176		3.7574	227.31	19.048
	1.1210	49.352	14.252		4.0379	269.78	20.471
	1.2665	56.946	14.325		4.2491	313.68	22.151
	1.4261	65.684	14.409	373.15	0.1026	3.430	16.093
	1.5619	73.932	14.502		0.3831	13.038	16.168
	1.7123	83.194	14.605		0.6707	23.289	16.173
	1.8563	92.724	14.716		0.9512	33.718	16.295
	2.0028	103.81	14.894		1.2366	44.833	16.412
	2.2154	120.83	15.152		1.5198	55.969	16.515

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
$x_{HFC\text{-}125} = 0.7498$				398.15	3.7677	146.42	19.285
373.15	1.8158	68.558	16.705		4.0838	162.22	19.674
	2.1451	82.979	16.913		4.4104	179.33	20.138
	2.4423	97.037	17.161		4.7032	195.85	20.583
	2.7126	110.59	17.381		4.9995	213.12	21.105
	3.0417	127.97	17.745		5.2832	230.86	21.623
	3.3230	144.17	18.061		5.5482	248.01	22.218
	3.5839	160.13	18.449		5.8797	270.34	23.045
	3.8295	176.40	18.893		6.1089	286.73	23.721
	4.0899	194.34	19.363	423.15	0.1026	3.006	18.016
	4.3834	217.22	20.065		0.3871	11.511	18.097
	4.5949	234.64	20.600		0.6820	20.538	18.144
	4.8513	257.52	21.354		1.0195	31.158	18.250
	5.0590	279.05	22.128		1.4116	43.932	18.351
	5.2713	301.48	22.966		1.8097	57.012	18.572
398.15	0.1015	3.173	17.113		2.1813	69.700	18.737
	0.4385	13.950	17.185		2.4719	80.052	18.932
	0.7835	25.371	17.224		2.7225	89.117	19.039
	1.1196	36.415	17.384		3.0801	102.42	19.330
	1.4667	49.215	17.526		3.3882	114.28	19.564
	1.8622	63.986	17.675		3.6927	126.33	19.839
	2.1801	76.205	17.844		3.9808	138.19	20.073
	2.5538	91.223	18.108		4.2443	151.32	20.418
	2.8222	102.64	18.316		4.6056	165.01	20.825
	3.1684	117.93	18.651		4.9136	178.95	21.124
	3.4644	131.77	18.898		5.2529	194.60	21.618

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
	$x_{HFC\text{-}125}$ = 0.7498			323.15	1.4687	56.164	14.263
423.15	5.5211	207.39	21.992		1.6762	66.168	14.369
	5.8390	222.90	22.466		1.8567	75.610	14.479
	6.1025	236.39	22.972		2.0678	87.939	14.609
	6.4329	253.47	23.529		2.2032	96.252	14.735
	6.8112	273.66	24.218		2.3439	105.80	14.886
	7.1132	290.18	24.905		2.5003	117.51	15.075
	7.4111	306.89	25.535	348.15	0.1011	3.028	15.150
	$x_{HFC\text{-}125}$=0.4998				0.1013	3.031	15.155
298.15	0.1015	3.568	13.057		0.4009	12.283	15.169
	0.1978	7.046	12.981		0.7115	22.380	15.225
	0.3468	12.620	12.991		1.0162	32.866	15.281
	0.4936	18.373	12.984		1.3257	44.177	15.364
	0.6397	24.396	12.992		1.6057	54.815	15.470
	0.7819	30.753	12.996		1.9352	68.454	15.620
	0.9278	37.595	13.023		2.2757	83.837	15.834
	1.0748	44.824	13.053		2.5173	95.523	15.996
	1.2311	53.079	13.069		2.7272	107.05	16.188
	1.3799	61.836	13.139		2.9301	117.83	16.438
323.15	0.1018	3.291	14.093		3.1883	133.84	16.774
	0.2958	9.752	14.066		3.4038	148.49	17.073
	0.4898	16.495	14.080		3.6231	165.08	17.482
	0.6841	23.565	14.092		3.8501	184.21	18.003
	0.8796	31.046	14.113		4.0520	204.99	18.554
	1.0797	39.147	14.152		4.2104	223.42	19.193
	1.2707	47.208	14.194		4.3256	238.84	19.685

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
	$x_{HFC\text{-}125}$=0.4998			398.15	0.1018	2.658	17.275
348.15	4.4789	262.96	20.517		0.4106	10.874	17.305
	4.5844	283.44	21.340		0.7564	20.369	17.381
373.15	0.1021	2.848	16.231		1.0879	29.800	17.480
	0.3485	9.861	16.275		1.4116	39.347	17.541
	0.5945	16.927	16.320		1.6916	47.912	17.640
	0.9066	26.596	16.360		2.3044	67.809	17.903
	1.2179	36.436	16.445		2.6481	79.793	18.097
	1.5324	46.856	16.546		2.7329	82.854	18.154
	1.8384	57.363	16.675		3.0372	92.257	18.361
	2.1432	68.560	16.828		3.3691	104.34	18.581
	2.5136	82.782	17.052		3.6685	116.02	18.860
	2.8252	95.469	17.253		4.0250	130.31	19.131
	3.1902	111.44	17.586		4.3743	145.16	19.472
	3.4674	124.33	17.781		4.6942	159.28	19.901
	3.8625	144.06	18.297		5.1529	181.07	20.515
	4.1785	161.74	18.742		5.4597	196.29	20.952
	4.4256	176.45	19.094		5.7776	213.22	21.464
	4.6983	194.28	19.613		6.1243	231.99	22.084
	4.9317	210.15	20.139		6.4572	251.85	22.774
	5.2083	230.90	20.780		6.7770	271.53	23.480
	5.4675	252.45	21.563		7.0381	288.55	24.157
	5.7579	279.07	22.527	423.15	0.1015	2.490	18.346
	5.9959	303.41	23.465		0.3432	8.416	18.430
	6.2043	327.28	24.462		0.5835	14.575	18.453
	6.3614	345.03	25.322		0.8777	22.174	18.527

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
423.15	1.2583	32.282	18.626	298.15	0.7919	24.663	12.833
	1.5547	40.387	18.709		0.9304	30.225	12.805
	1.8254	47.984	18.811		1.0823	36.040	12.799
	2.1330	56.862	18.930		1.2358	42.486	12.858
	2.4385	66.196	19.072		1.3637	48.208	12.852
	2.8285	78.376	19.242	323.15	0.1013	2.620	14.017
	3.1177	87.898	19.423		0.2925	7.704	13.999
	3.4579	99.369	19.660		0.4879	13.110	13.974
	3.7682	106.97	19.917		0.6784	18.606	13.979
	4.0878	117.68	20.134		0.9010	25.361	13.999
	4.3634	127.22	20.343		1.1231	32.512	14.016
	4.6771	138.80	20.611		1.3094	38.795	14.044
	4.9609	148.97	20.845		1.4691	44.556	14.064
	5.2206	158.61	21.112		1.6396	50.924	14.130
	5.5227	170.56	21.405		1.9684	64.349	14.240
	5.8070	181.72	21.784		2.1371	72.037	14.333
	6.0780	192.73	22.117		2.2682	78.372	14.402
	6.3841	205.30	22.516		2.4382	87.380	14.541
	6.7408	220.08	23.045		2.5998	96.654	14.677
	7.0130	232.67	23.419		2.7081	103.49	14.769
	$x_{HFC\text{-}125} = 0.2475$			348.15	0.1020	2.443	15.059
298.15	0.1012	2.856	12.914		0.3010	7.315	15.017
	0.2255	6.445	12.855		0.4958	12.288	15.029
	0.3741	10.912	12.846		0.6933	17.365	15.036
	0.4925	14.618	12.842		0.8994	22.917	15.051
	0.6456	19.620	12.809		1.1207	29.117	15.102

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
348.15	1.3405	35.540	15.147	373.15	1.9098	47.703	16.425
	1.5646	42.277	15.204		2.1515	54.633	16.509
	1.7656	48.602	15.229		2.4068	62.182	16.608
	1.9503	54.711	15.314		2.6395	69.494	16.734
	2.1869	62.889	15.404		2.8869	77.470	16.850
	2.3697	69.454	15.488		3.1850	87.565	17.013
	2.5714	77.050	15.601		3.4382	96.604	17.181
	2.7443	84.104	15.687		3.6556	105.17	17.345
	2.9469	92.724	15.839		3.8694	113.13	17.484
	3.2165	105.26	16.046		4.1507	124.68	17.816
	3.4231	115.55	16.282		4.4407	137.86	18.107
	3.6220	126.31	16.542		4.6753	148.99	18.399
	3.8239	138.50	16.732		4.8597	158.39	18.641
	4.0105	150.64	17.048		5.1239	172.00	19.043
	4.2194	166.29	17.454		5.3158	183.26	19.430
	4.4608	187.30	17.454		5.5278	196.17	19.789
	4.6069	202.64	18.540		5.7789	213.45	20.382
	4.8006	221.45	19.431		5.9879	228.19	20.889
373.15	0.1010	2.263	16.125		6.1579	241.47	21.420
	0.2897	6.532	16.124		6.3636	258.43	22.096
	0.4870	11.106	16.123		6.5311	273.39	22.726
	0.6837	15.774	16.157		6.7264	292.34	23.521
	0.9279	21.736	16.189		6.8884	309.39	24.329
	1.1694	27.826	16.249		6.9884	324.13	24.858
	1.4166	34.189	16.285	398.15	0.1015	2.119	17.181
	1.6655	40.906	16.334		0.3715	7.852	17.250

Table 1 (continued)

T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s	T / K	P / MPa	ρ / kg m^{-3}	η / μ Pa s
398.15	0.6626	14.191	17.270	423.15	0.4896	9.746	18.307
	0.9476	20.571	17.328		0.7802	15.694	18.327
	1.2239	26.935	17.373		1.0668	21.692	18.398
	1.5278	34.052	17.412		1.3617	28.006	18.433
	1.8243	41.213	17.516		1.6553	34.446	18.510
	2.1660	49.767	17.651		1.9441	40.720	18.604
	2.4391	56.886	17.682		2.2611	47.930	18.659
	2.7233	64.467	17.842		2.5568	54.688	18.770
	3.0300	72.919	17.975		2.8355	62.201	18.844
	3.3768	82.801	18.163		3.1914	70.063	19.006
	3.7013	92.673	18.336		3.4575	76.901	19.156
	4.0016	102.00	18.515		3.7506	84.314	19.313
	4.2940	111.43	18.749		4.0859	93.237	19.444
	4.6289	122.96	18.972		4.3958	101.89	19.642
	4.9136	133.14	19.230		4.6695	109.44	19.846
	5.1899	143.31	19.492		5.0060	119.07	20.075
	5.4971	155.24	19.844		5.2855	127.41	20.251
	5.7874	166.93	20.192		5.5514	135.51	20.498
	6.0235	177.12	20.478		5.8943	146.29	20.777
	6.2584	187.14	20.822		6.2655	158.17	21.104
	6.5085	198.57	21.187		6.6209	170.14	21.484
	6.7783	211.37	21.636		6.9002	180.04	21.753
	7.0231	223.77	22.065		7.2113	191.16	22.228
	7.2564	235.10	22.460		7.5099	202.01	22.498
423.15	0.1018	1.999	18.268		7.7205	210.30	22.831
	0.2910	5.751	18.298				

Table 2 Scaling parameters for HFC-125 and HFC-32

i - j	ε /k [K]	σ [nm]
HFC-125 – HFC-125	235.85	0.52600
HFC-32 – HFC-32	277.46	0.41530
HFC-125 – HFC-32	265.25	0.46024

Table 3 Constants in Eqs.(1)-(4)

	HFC-125	HFC-32
a_{10}	-8.736826×10^{-5}	1.581357×10^{-5}
a_{11}	8.042472×10^{-2}	3.667580×10^{-2}
a_{12}	-1.56065×10	-1.511928×10
a_{20}	-3.957473×10^{-7}	2.629959×10^{-6}
a_{21}	4.434098×10^{-4}	-2.049982×10^{-3}
a_{22}	-9.014753×10^{-2}	4.362916×10^{-1}
a_{30}	4.536891×10^{7}	-2.413426×10^{-6}
a_{31}	-4.307842×10^{-4}	1.236867×10^{-8}
a_{32}	9.75525×10^{-2}	-1.602793×10^{-11}

Table 4 Prediction results of VW method with two mixing rules for HFC-125 + HFC-32 mixtures.

		original mixing rule for χ_{ij}			mixing rule of Eqs.(6)-(8)		
	n.d.[1]	BIAS (%)[2]	AAD (%)[3]	MAX (%)[4]	BIAS (%)	AAD (%)	MAX (%)
HFC-125	132	-0.023	0.20	1.3	-0.023	0.20	1.3
HFC-32	115	-0.017	0.30	-1.1	-0.017	0.30	-1.1
Mixture							
$X_{HFC-125}$							
0.7498	109	-0.28	0.37	-0.94	-0.28	0.32	-0.94
0.4998	114	0.16	0.40	1.2	0.16	0.40	-1.0
0.2475	134	0.15	0.33	3.3	0.14	0.33	2.8

1) n.d. : number of data

2) BIAS(%) = $\Sigma(\eta_{exp} - \eta_{cal})/\eta$ x100/ n.d.

3) AAD (%) = $\Sigma\ |(\eta_{exp} - \eta_{cal})|/\eta_{cal}$ x100/ n.d.

4) MAX(%) = maximum of AAD.

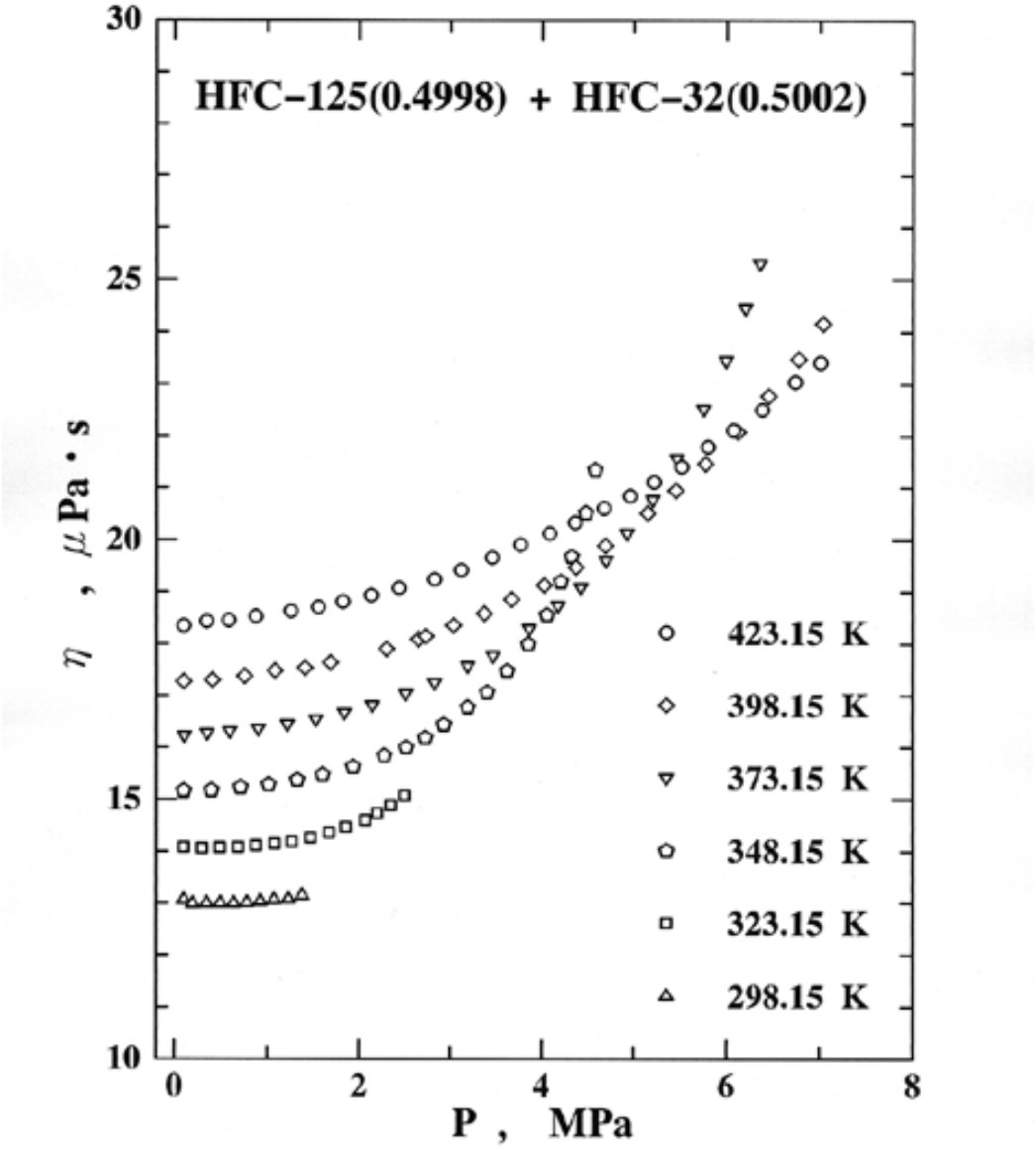

Fig.1 Viscosity of the binary gaseous mixture of HFC-125(0.4998)+HFC-32(0.5002) as a function of pressure.

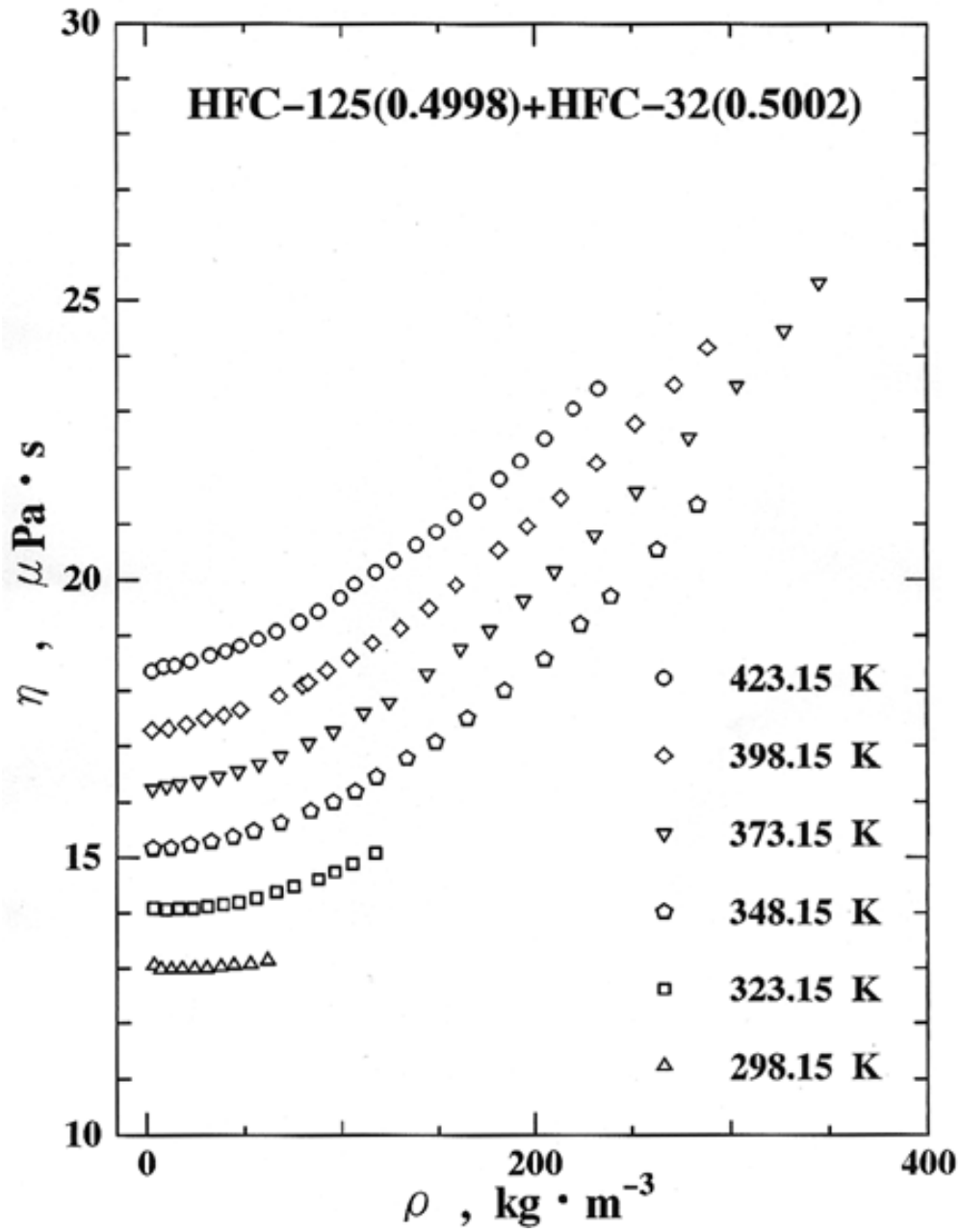

Fig.2 Viscosity of the binary gaseous mixture of HFC-125(0.4998)+HFC-32(0.5002) as a function of density

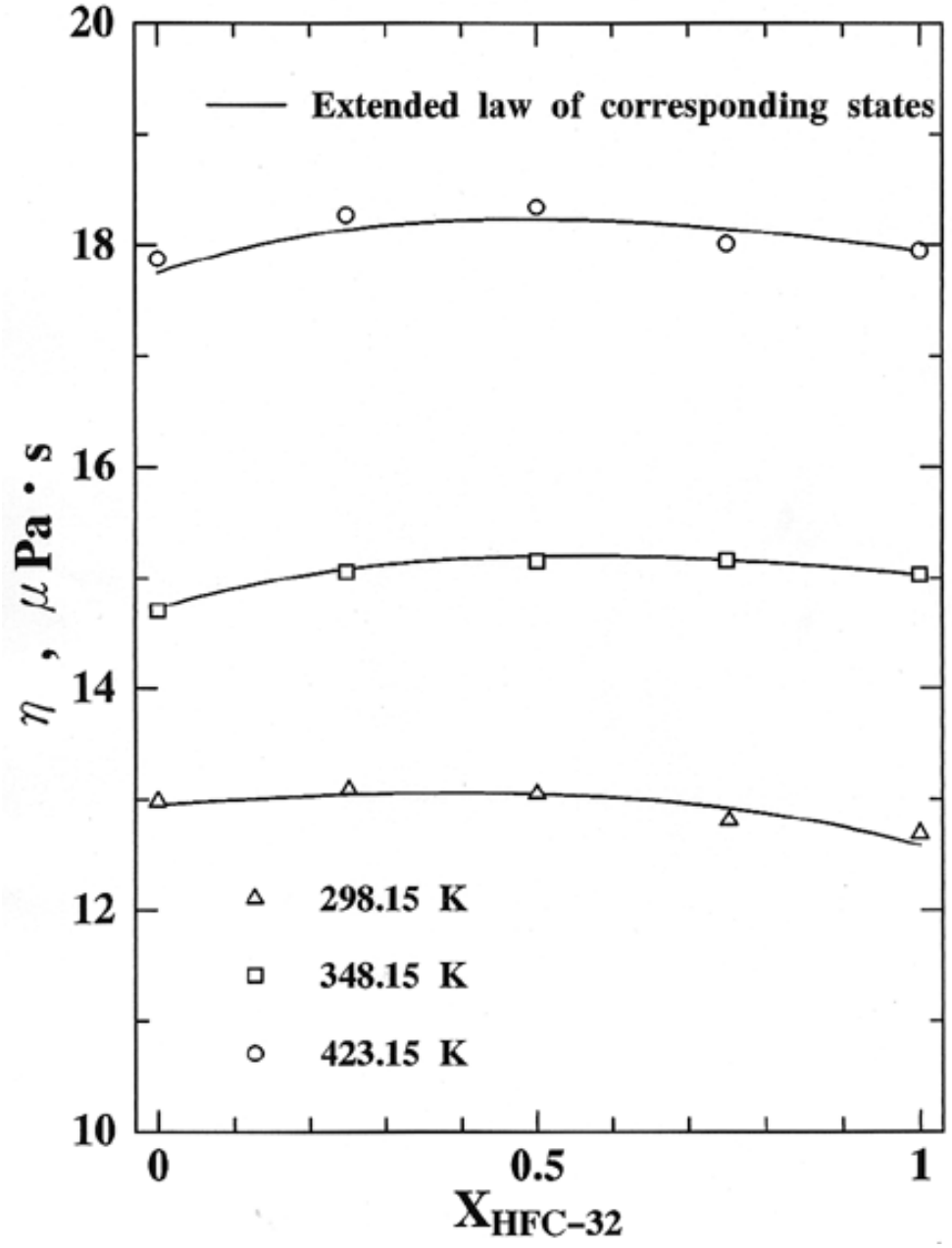

Fig.3 Viscosity of the gaseous mixtures of HFC-125 + HFC-32 at 0.1 MPa.